N87-16415

MEASUREMENT OF MINORITY CARRIER LIFETIME, MOBILITY AND DIFFUSION LENGTH IN HEAVILY DOPED SILICON

STANFORD UNIVERSITY

S. E. Swirhun and R. M. Swanson

Outline

Introduction

Measurement of Minority Carrier Lifetimes in p^+ and n^+ Si

- photoluminescence decay technique
- data reduction
- fits of lifetime vs. doping data (p^+ and n^+)

Measurement of Diffusion Length and Mobility in p^+ and n^+ Si

- lateral transistor test structure
- typical diffusion length data
- diffusion length vs. doping in p^+ Si
- electron (minority carrier) mobility vs. doping
- hole (minority carrier) mobility vs. doping

Minority Carrier Lifetime in n^+ and p^+ Silicon Recombination Paths

- Shockley-Read-Hall Recombination

$$\tau_p = (N_t v \sigma)^{-1}$$

  – lifetime independent of doping, dependent on N_t

- Auger Recombination: Trap Assisted

$$\tau_p = (T_n n N_t)^{-1}$$

  – lifetime dependent on doping, N_t

- Auger Recombination: Band to Band

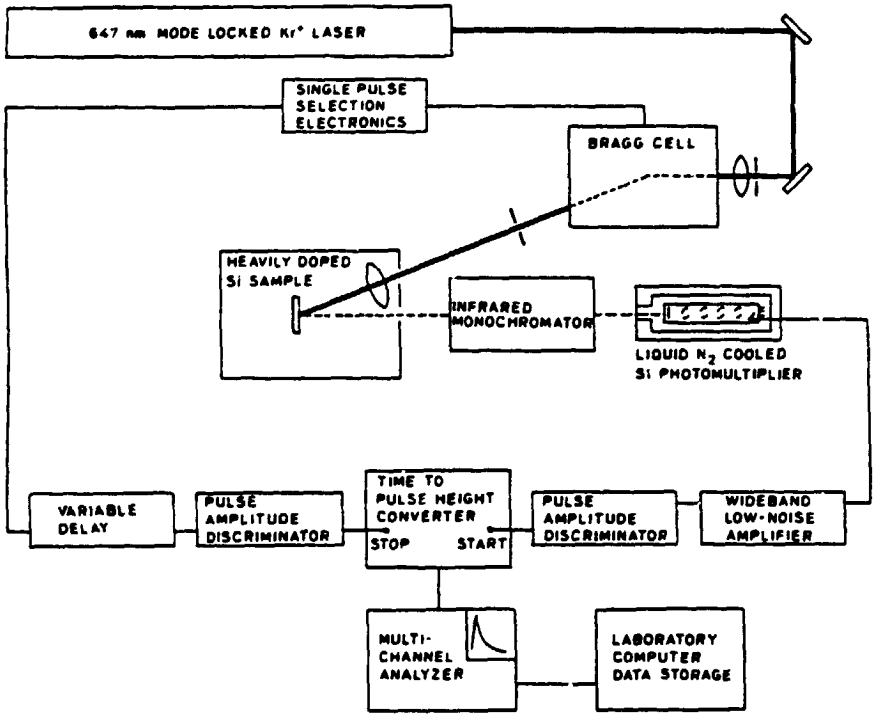
$$\tau_p = (C_n n^2)^{-1}$$

  – lifetime dependent on doping only

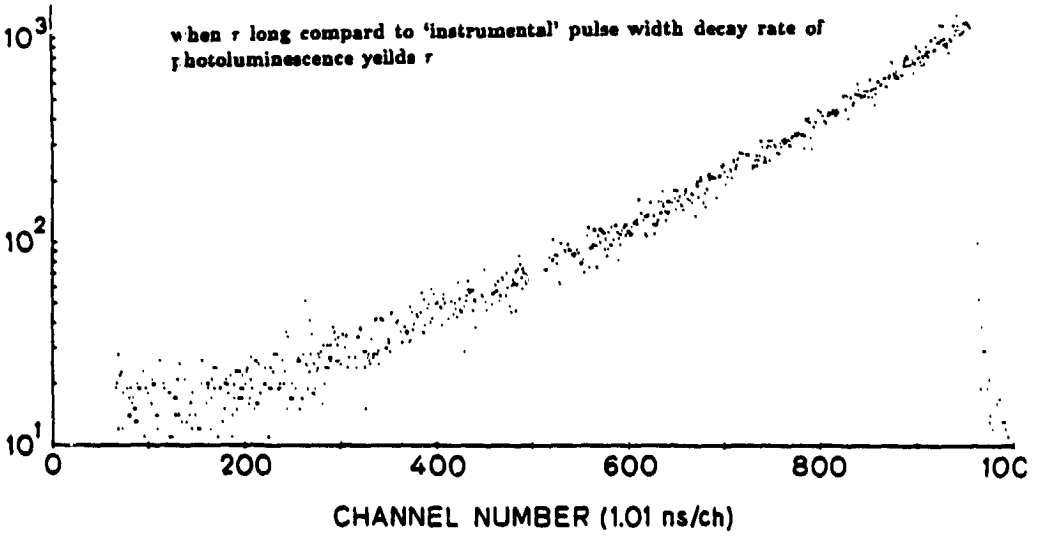
Photoluminescence Lifetime Decay

- short (200 ps) laser pulse generates minority carriers
- monitor decay of luminescence radiation

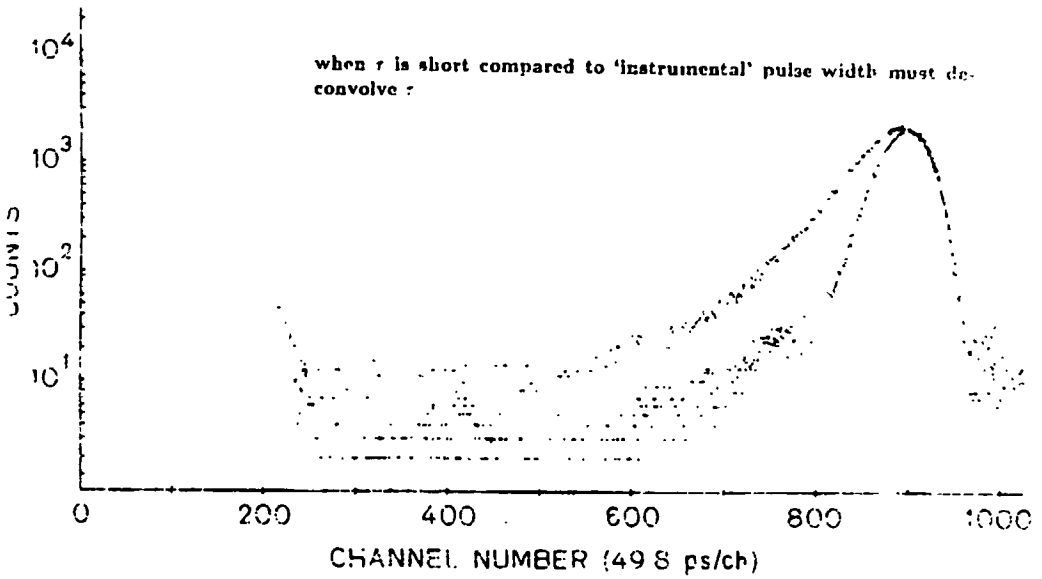
Photoluminescence Decay Lifetime Measurement Apparatus



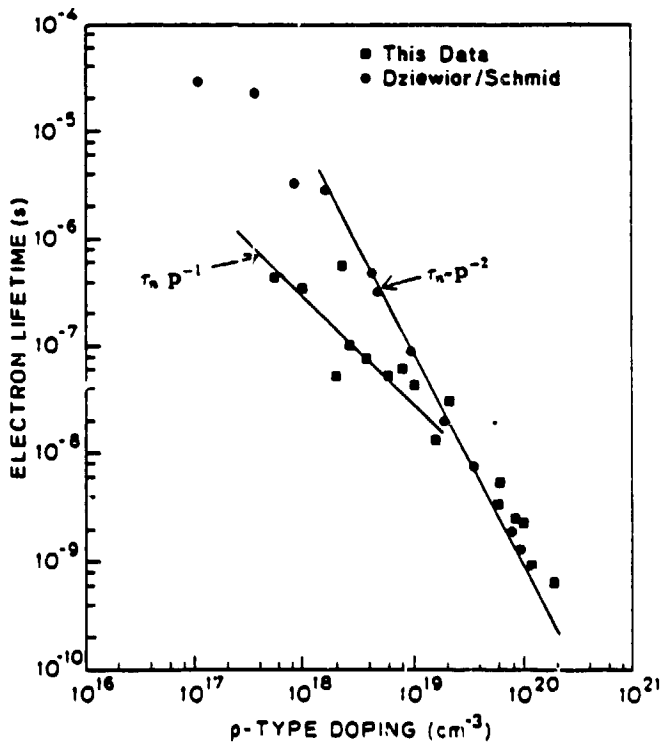
Photoluminescence Decay
Si:Sb $4.2 \cdot 10^{18}$
τ = 160 ns ± 10%



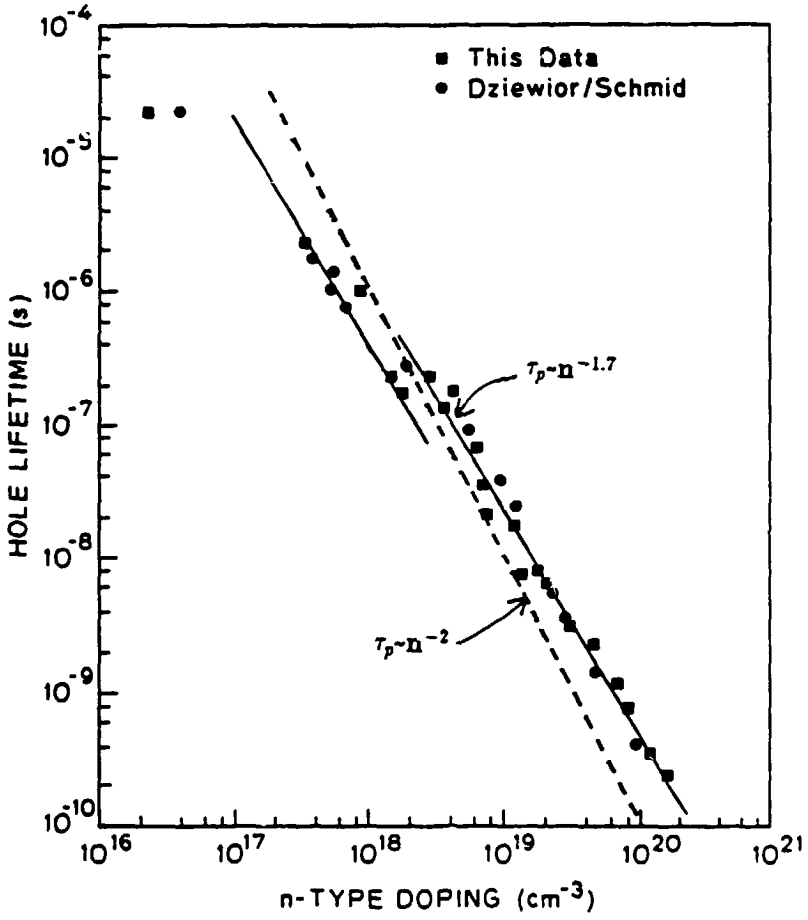
Photoluminescence Decay
Si:Ph $9.2 \cdot 10^{19}$
τ = 880 ps ± 20%



Electron Lifetime in p-Type Silicon



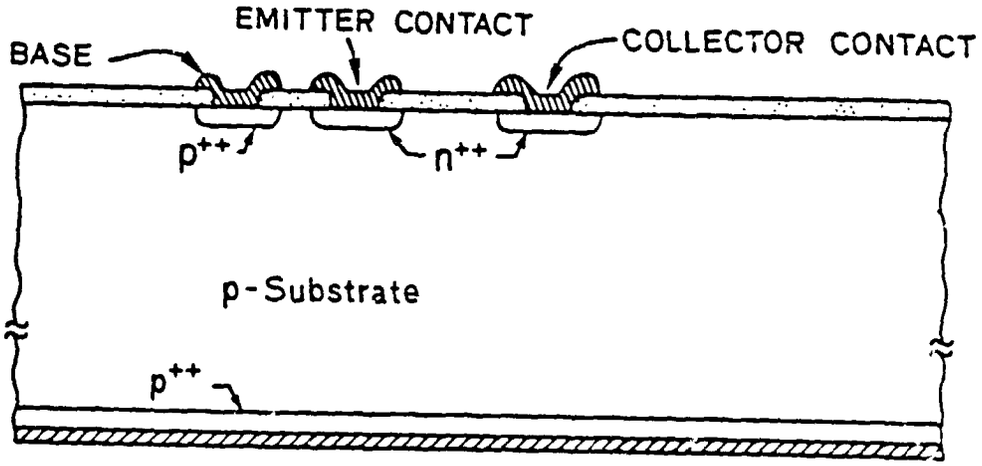
Hole Lifetime in n-Type Silicon



Measurement of Diffusion Length and Mobility

- Diffusion Length (electrons in p^+ Si) $L_n = \sqrt{D_n \tau_n}$
- Mobility (electrons in p^+ Si) $\mu_n = q/kT\ D_n$

Lateral Transistor to Measure L_n

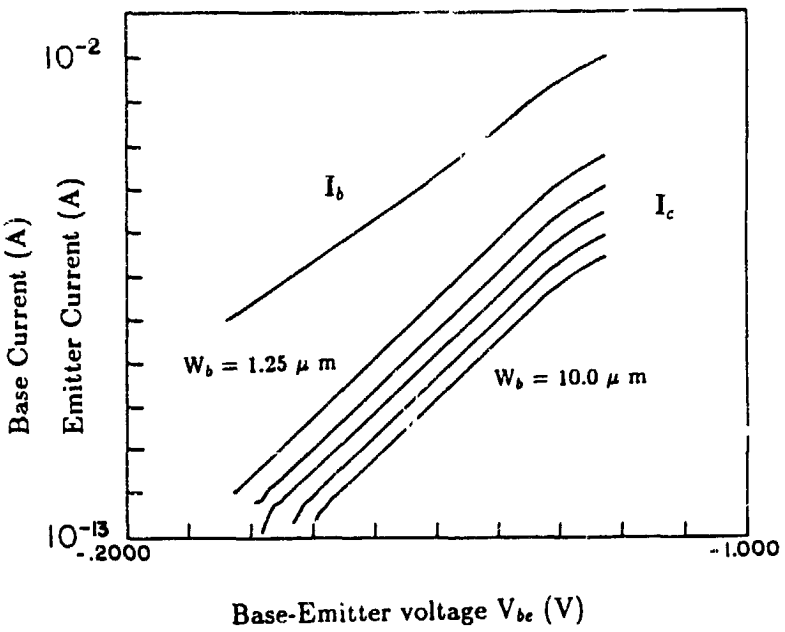


$$I_c = I_{c0}(e^{(qV_{be}/kT)} - 1)$$

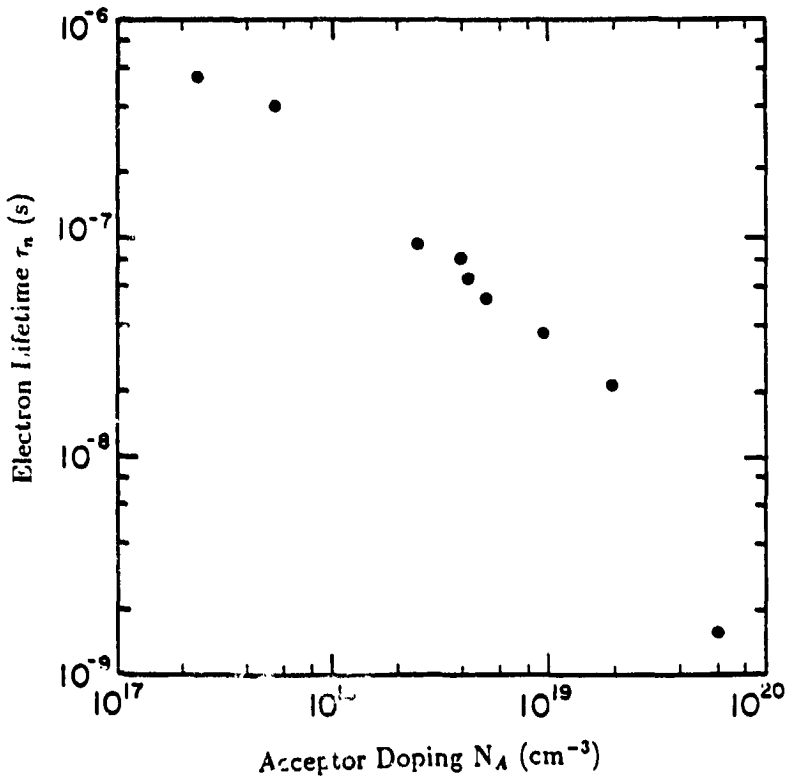
$$I_{c0} = \frac{qAn_0D_n}{L_n}e^{-(W_b/L_n)} \qquad \text{when } W_b >> L_n$$

use similar structures v 'th varying W_b to obtain L_n

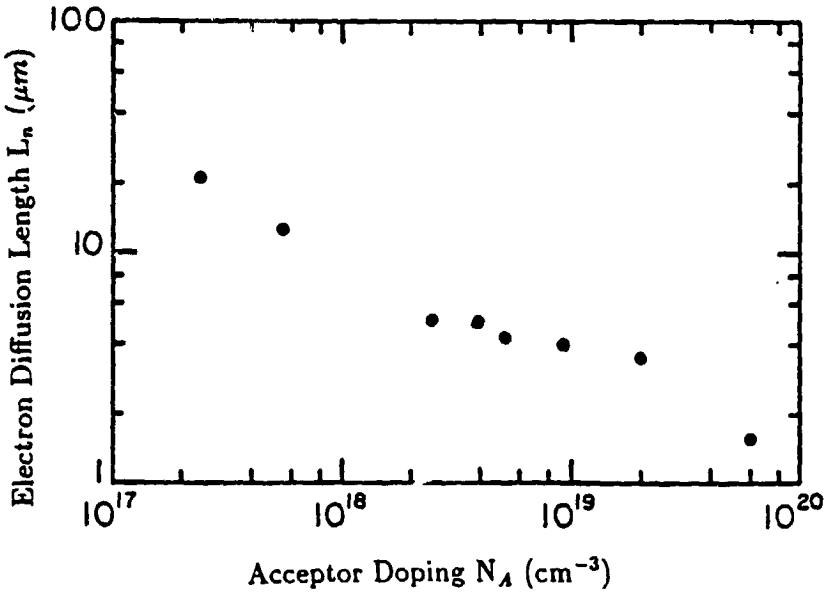
Gummel Plot of Lateral Bipolar Transistors



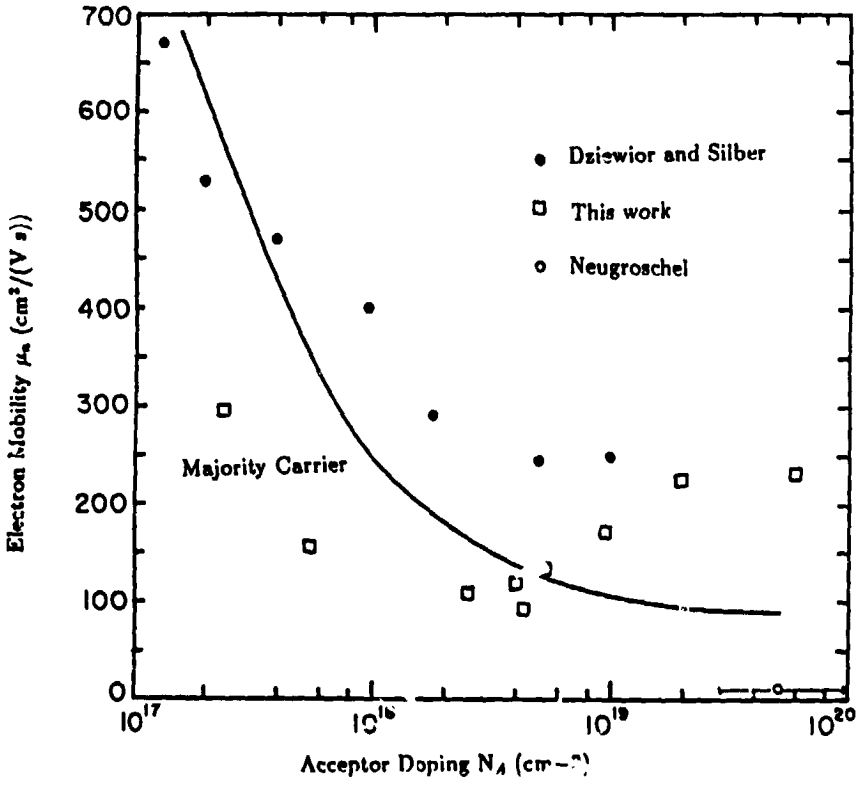
Electron Lifetimes of L_n Samples



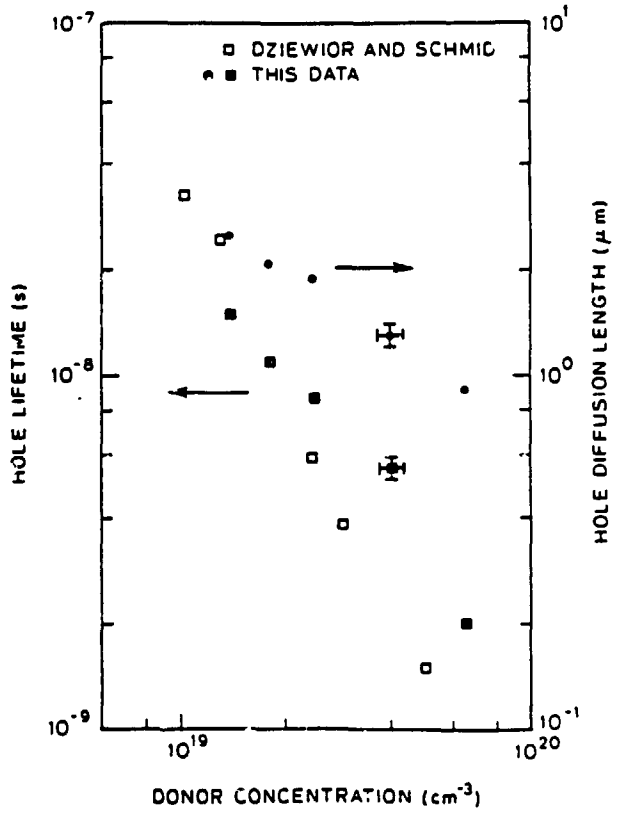
Extracted Electron Diffusion Lengths



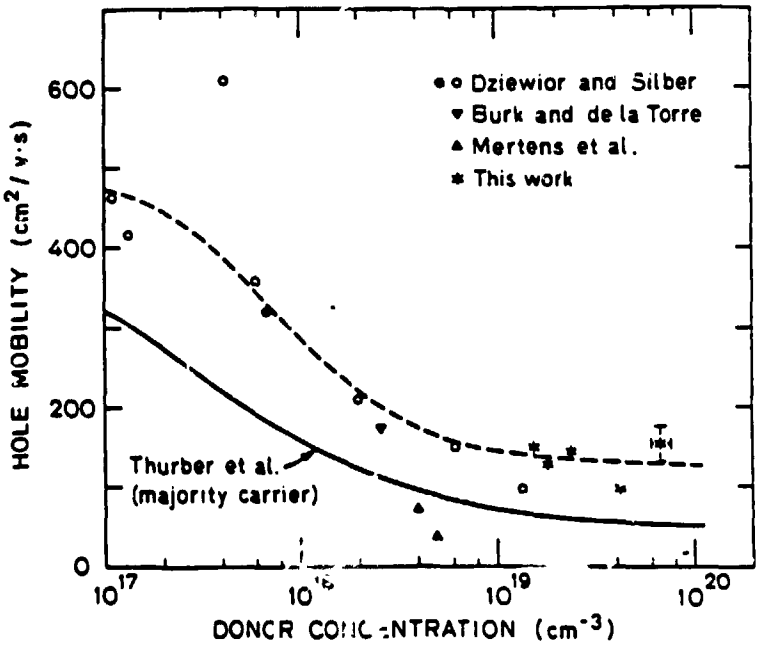
Electron Mobility at 300°K



Lp and τp in Heavily Doped Epitaxial Silicon



Hole Mobility in P epi Silicon



Conclusions

Lifetime in heavily doped Si

- **first comprehensive measurements of τ_n, τ_p in *processed* heavily doped Si**
- **τ measurements extended into 10^{20} cm^{-3} doping range**
- **photoluminescence decay technique suitable and accurate**
- **τ_n in p^+ Si**
  - **'standard' τ_n dependence with N_A^{-2} accurate in very limited range**
  - **lifetime modeled best by sum of inverse plus inverse square dependence on N_A**
- **τ_p in n^+ Si**
  - **previously observed τ_p dependence verified**
  - **use of N_D^{-2} dependence inadequate for wide doping range**
  - **data suggests better fit lifetime dependence of approximately $N_D^{-1.7}$**

Diffusion Length and Mobility Measurement

- **lateral transistor test structure used to measure L_n, L_p**
- **measurement of lifetimes allows extraction of μ_n, μ_p**
- **extraction of μ_n, μ_p in 10^{19} range shows that minority carrier mobilities exceed majority carrier mobilities**